PROPOSED I.E.S. CONFERENCE PAPER

# "Effect of Metal Iodide Additives on High Pressure Mercury Lamps"

May, 1964

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The use of metal salts as additives to the mercury discharge has been the subject of several previous papers 1,2,3,4, and presentations at several technical conferences 5,6,7,8. The authors of this paper have established several conditions for a practical lamp. Among these were the following: (1) Operation from all existing mercury lamp ballasts, (2) Operation in any position, (3) Maximum light output consistent with the previous two criteria. The construction and characteristics of such a lamp are discussed in this paper. Part of the work toward this goal involved investigation of various materials as additives. The most interesting of these is also reviewed.

In the high pressure mercury discharge the particles are in a state of thermal equilibrium at a temperature of about 6000°K. Under these conditions the mercury atoms, in collisions with electrons, are excited to energy states which then radiate their characteristic lines. These energy states are populated according to their energy in a manner described by Boltzman's Law. Plotted in Fig. 1 are the relative concentrations versus the energy of the states at a discharge temperature of 6000°K.

The mercury level which radiates the strong visible lines is 7.7 ev above ground and its concentration is less than one millionth that of the ground state. If atoms which have their excited states much lower in energy than mercury are added to the discharge their radiation will become important at much lower neutral atom densities. Thus, thallium metal at only 50 microns pressure will radiate the 5350A line with an intensity comparable to the mercury visible lines even though the mercury density is many thousand times greater.

In our earlier paper (1) before this conference we showed that the pressure of thallium could be increased by the use of thallium iodide and that most of the visible radiation could be concentrated in the 5350A line, and that the efficiency of the discharge was increased to greater than 80 lpw.

Many other metals have iodides whose vapor pressure is much greater than that of the metal. Included among them are gallium, indium and thorium. There are also metals such as sodium, potassium and lithium which cannot be used because of their reactivity with the quartz. The iodides of these materials, however, permit their use, although in the Na and K cases the pressure is considerably reduced.

We have found a large number of metals, which by the use of their iodides, may be introduced into the high pressure mercury discharge to modify the spectral output. Several examples of what may be accomplished in changing the spectral distribution and color are given in Figs. 2 & 3. These show the tracings of spectral distribution curves which were obtained using a flat response detector, and cover the region from 4100A to 20,000A. (a) standard mercury lamp; (b) Hg + Ga iodide, which is a pale blue discharge with strong lines in the violet; (c) Hg + In iodide which is a deep blue; (d) Hg + Tl iodide which is green; (e) Hg + Na iodide with strong yellow emission; and (f) Hg + Li iodide which is pink in appearance. The luminous efficiencies of these lamps in 400W size range from 20 lpw to 80 lpw.

It is possible to combine two or more of these additives to improve color rendition or efficiency. In Fig. 4 we show a spectrum of the combination of Hg + NaI + TlI. This combination results in both improved color rendition and efficiency. This combination has been operated in the laboratory at efficiencies up to 120 lpw at 0 hours and lamps operating at 90 lpw at 100 hours have been developed and tested.

The color and efficiency of this lamp is dependent upon the minimum bulb wall temperature since the lines of the two components do not increase uniformly as their vapor pressures are increased. Since thallium iodide has considerably higher vapor pressure than sodium iodide, at the lower temperatures the 5350A thallium line is much stronger. With increasing temperature, the Na line increases in intensity and becomes stronger than the 5350A line adding yellow and orange to the spectrum and increasing the efficiency.

The ratio of 5890 to 5350A lines and their luminous efficiency as the oven temperature in which the arc tube is operating is increased are shown in Fig. 5. At the higher temperatures the sodium lines at 5688 and 6154 are appearing and the "D" line is being partly absorbed. The lamp efficiency is seen to increase from 70 to 110 lpw.

In the development of a practical iodide additive mercury lamp many problems arise which are not normally encountered in the production of standard mercury lamps. Most of these basic problems were first met in the design of a thallium iodide mercury additive lamp (1). When sodium iodide was introduced into the mercury discharge the following problems became increasingly severe and their solutions much more difficult: (1) keeping the metal additive in the vapor state during operation in the lamp; (2) preventing the additive from attacking arc tube parts; (3) starting and maintaining the lamp discharge on all conventional ballasts; and (4) operating the lamp in any position.

PROBLEM 1: As noted earlier in this paper, the vapor pressure of sodium iodide is lower than that of sodium; thus, it becomes necessary to have a higher minimum temperature to provide the required sodium iodide pressure.

In order to maintain sodium iodide in the discharge and keep a proper pressure balance between the two metal additives and mercury, two steps were taken. First, the outer bulb was evacuated to reduce the heat loss from the arc tube and thereby elevate the quartz wall temperature. Also, a barium getter was flashed inside the outer bulb to maintain a high degree of vacuum throughout lamp life. Secondly, metal end caps with an insulating, low vapor pressure, high melting point, white reflecting surface, material were placed over each end of the quartz arc tube.

Thus, by raising the temperature of the arc tube over its entire length and by increasing the temperature at the arc tube ends (cold spots), it was found that the proper pressure balance could be maintained between the major metal constituents. As illustrated by the spectral distribution curve Fig. 6 the differences in color of lamps with and without end caps are clearly brought forth. It can readily be seen that with the end caps the contribution by the sodium is considerably greater than in the case where no end caps are used.

PROBLEM 2: In the center of the arc discharge the sodium iodide breaks down into its elements sodium and iodine. These atoms are constantly moving out of the core and migrating in the direction of the quartz wall. Recombination between these sodium atoms and the iodine atoms (theoretically complete recombination) to form new sodium iodide molecules occurs before they can strike the wall. However, there is evidence that when standard size mercury arc tubes are used some free sodium atoms which have not been recombined with the iodine atoms do reach the wall of the arc tube and attack the quartz. Since the recombination of the sodium and iodine atoms depends to a great degree on the temperature gradient and distance of the arc core to wall, the structure of the arc tube can be altered to provide a longer path through the cooler areas to increase recombination. This was accomplished by increasing the diameter of the quartz tube by 4 mm. To maintain the arc tube loading (watts/$cm^2$) the arc length was decreased in the proper amount.

As sodium and iodine are so chemically active, normal oxide type electrodes were not usable and even thorium type electrodes, which were satisfactory for the thallium iodide lamps offered some problems. To date no electrode material, has been found to be more satisfactory than tungsten for use with Sodium-Thallium Iodide mercury additive lamps.

PROBLEM 3: It is absolutely necessary for a mercury lamp in order to be commercially practical that it have the ability to start and operate at any reasonable temperature and on any existing ballast designed for use with present type mercury vapor lamps. Additive lamps appear to be inherently harder to start; ie, requires higher initial line voltage to strike the arc, than the regular mercury lamps, so developing a Sodium-Thallium additive lamp which would start on 220V RMS or below at temperatures down to -20$^{\circ}$F was indeed a problem. This difficulty has been overcome by first making sure that additives used are pure and free of water vapor. Sodium iodide being extremely hygroscopic picks up much surface moisture as well as having considerable water of crystallization. Since even minute exposure to the atmosphere is enough to contaminate the additive, it is imperative that the additive be kept under vacuum or in a dry box at all times and be distilled into the arc tube during exhaust operations.

The second step taken to insure good starting was a radical change in the electrode design. By using a preheated cathode the starting of the lamp can be considerably improved and made practically independent of ambient temperatures. In this particular lamp design, the conventional resistor type starting circuit has been eliminated and a heater coil-electrode combination substituted (Fig 7). This circuit includes a bi-metal switch which cuts out the heater coil after a short period (10-20 secs) and allows the arc to operate normally from the main electrode. The bi-metal section of the switch is in the circuit at all times, so that the lamp current heats it sufficiently to keep the contacts open making it independent of heating by the lamp arc tube. The starting coil performs two functions; it provides initial heating to the arc tube which vaporizes the mercury helping to insure cold temperature starting. It also acts as an emitter and becomes a starting electrode until the switch opens, at which time it is cut out of the circuit and the main electrode takes over and operates in the usual manner. By this arrangement, starting can be achieved on any conventional ballast and at low temperatures.

PROBLEM 4: For a mercury vapor lamp to be practical, it should be able to operate in any position, since there are many applications for vertical burning in addition to the vast field of horizontal street lighting installations. As the temperature of the quartz wall of the arc tube will vary when the lamp is operated in different positions some means had to be found to maintain a near isothermal condition of the wall even though the lamp be varied from the vertical to horizontal position. As we described previously, the end caps served only to keep the end chambers at a constant temperature. The wall temperature in a horizontal burning position was found to be very much higher on the top section of the arc tube and cool enough on the bottom to allow condensation of the additive due to the natural bowing upward of the arc when operating in this position. To correct this condition a magnetic field was applied by the addition to the lamp fixture (Fig. 8), of a simple electro-magnet which forced the arc to return to approximately the center of the arc tube. This equalized the wall temperature at top and bottom. Thus the condensation of the additive was minimized and good color maintained.

The characteristics of the above described improved Sodium-Thallium additive mercury vapor lamp are shown in Table I.

This work represents another milestone in the use of and further development of metal iodides to improve the efficiency and color of the mercury vapor type lamp. Many problems still remain to be solved, but it is expected that with improved electrodes and other developments a lamp will be produced which will have a higher efficiency, an even more desirable color, and maintenance approaching that of the very excellent oxide electrode type lamp now in use. We can confidently look forward to a continued progress in the area of all arc discharge type light sources.

TABLE I

TABLE I

| | |
|---|---|
| Outer Bulb | BT37 clear(4-5/8" diameter) |
| Max. O.L. | 11-1/2" |
| L.C.L. | 7" |
| Base | Mogul Screw |
| Arc Length | 2-1/2" approx. |
| Volts | 135 approx. |
| Amps | 3.2 " |
| Rated Lamp Watts | 400 |
| Open Circuit Volts(min) | 220 R.M.S.(to-20°F) |
| Starting Current | 5 amps |
| Burning Position | any(1) |
| Initial Lumens | 36000(100hr) |

(1) When tilted more than 20° from vertical, a magnet is required.

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# Titles For Figures

Fig. I — Relative Concentrations of Atoms Excited to Higher States at 6000°K versus the Energy of These States.

Fig. II — Spectral Energy Distributions of Mercury, Mercury Plus Gallium Iodide, Mercury Plus Indium Iodide Lamps.

Fig. III — Spectral Energy Distribution of Mercury Plus Thallium Iodide, Mercury Plus Sodium Iodide, Mercury Plus Lithium Iodide Lamps.

Fig. IV — Spectral Energy Distribution of Mercury Plus Sodium Iodide and Thallium Iodide Lamps.

Fig. V — Ratio of Sodium and Thallium Principal Lines and Efficiency as a Function of Temperature.

Fig. VI — Effect of End Caps on the Spectral Distribution of Sodium-Thallium Iodide Lamps.

Fig. VII — Schematic Drawing of the Starting Circuit.

Fig. VIII — Effect of Magnet Field on Arc Bowing During Horizontal Operation.

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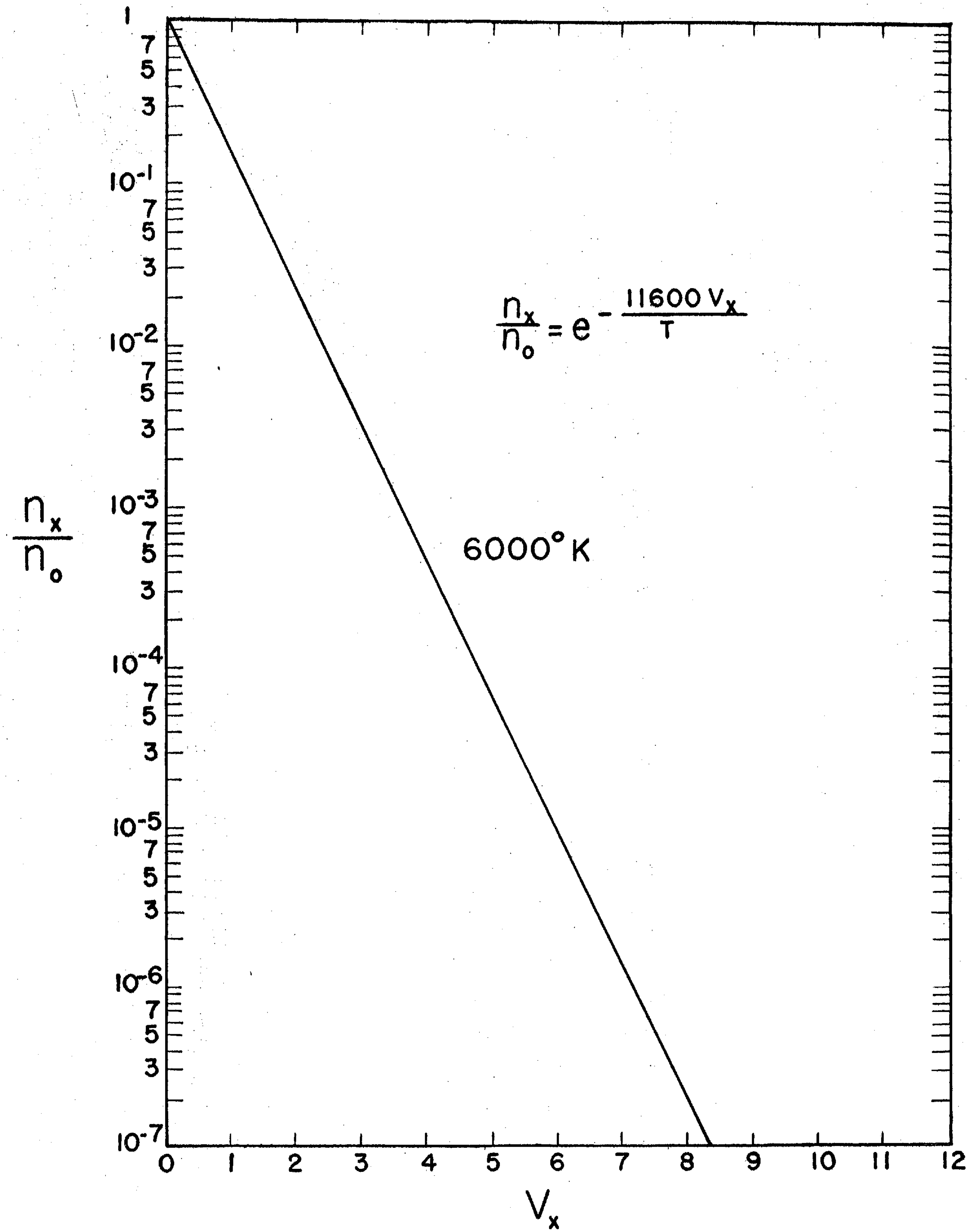
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$10^{-2}$
$10^{-3}$
$10^{-4}$
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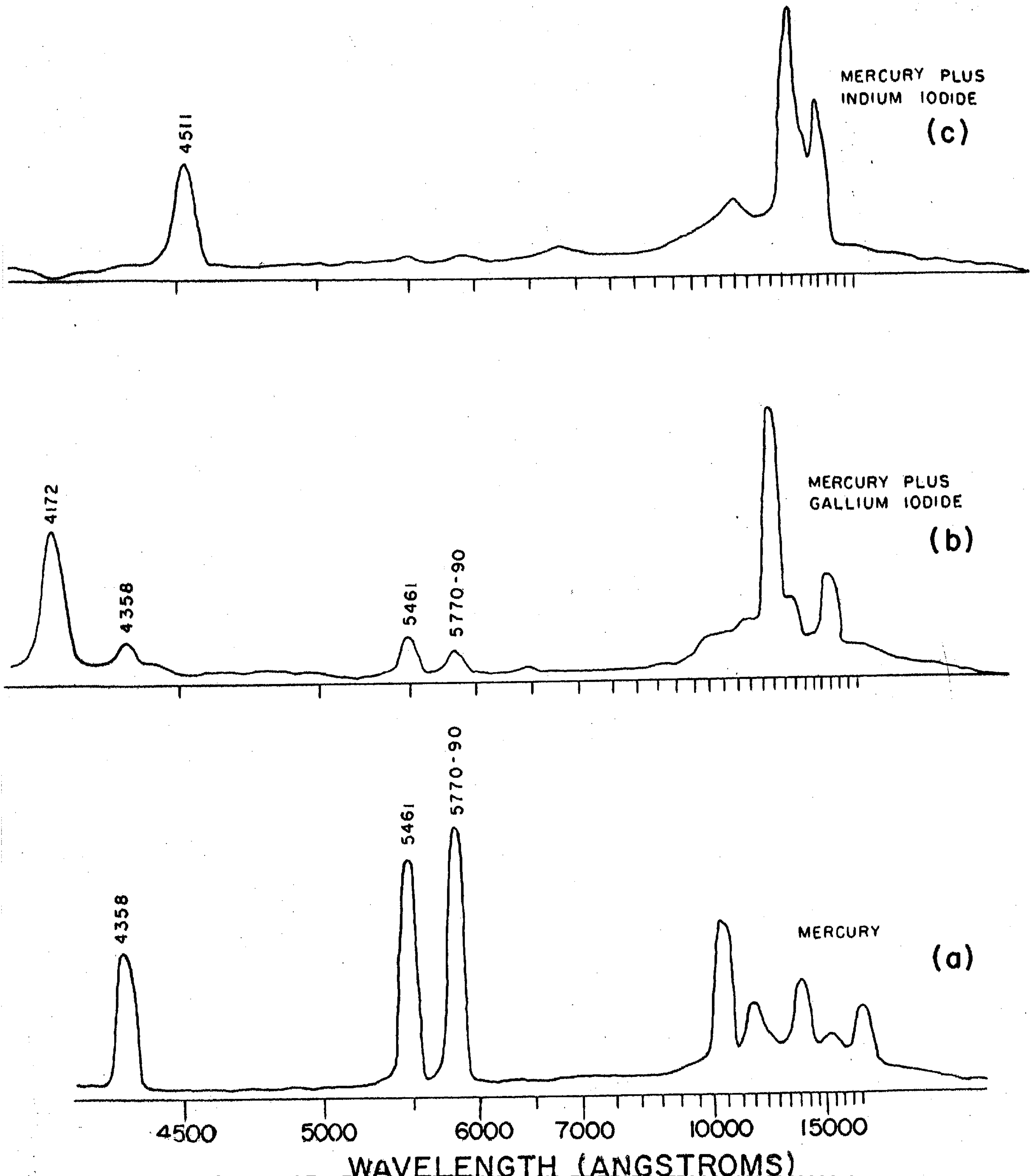
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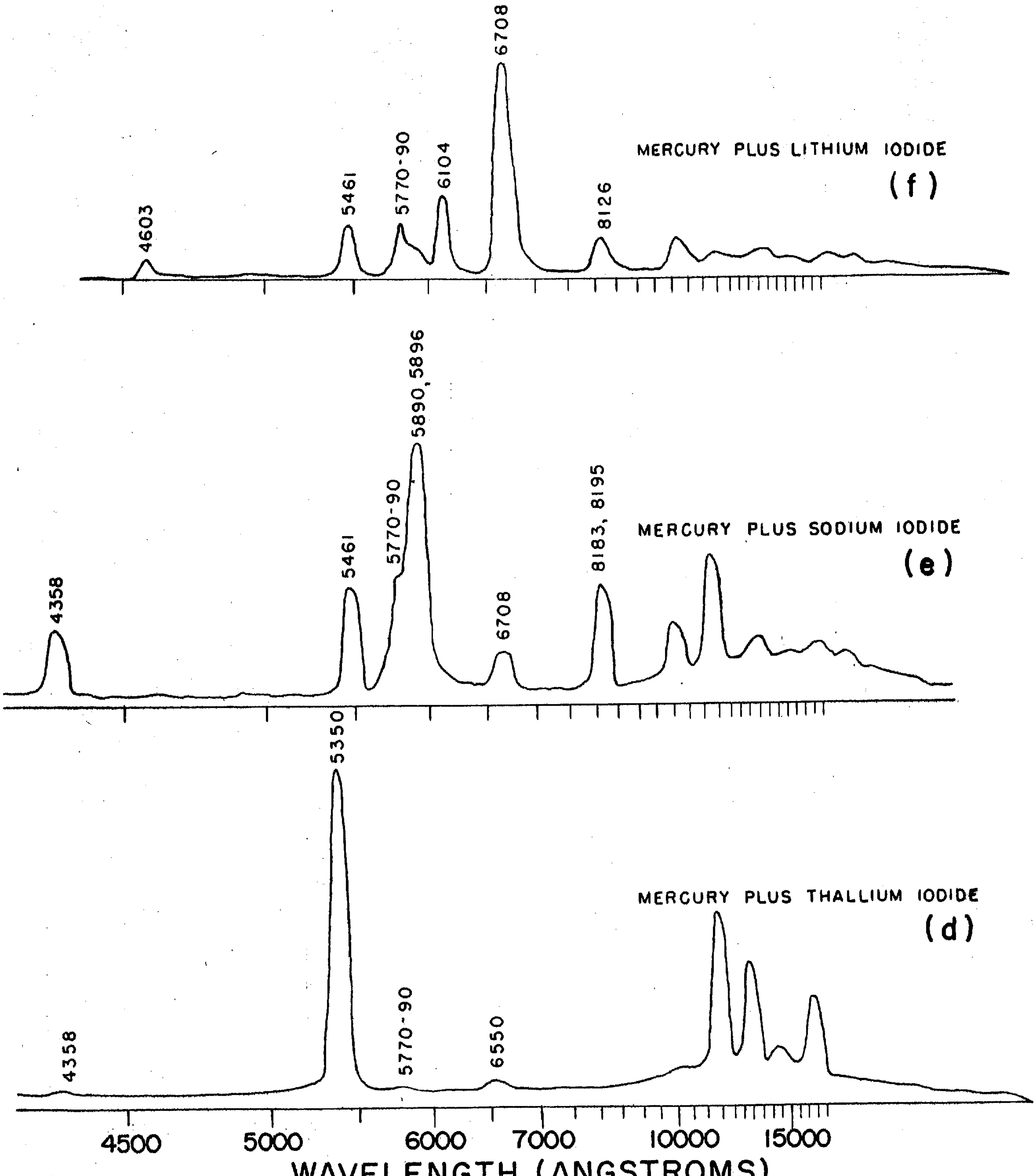
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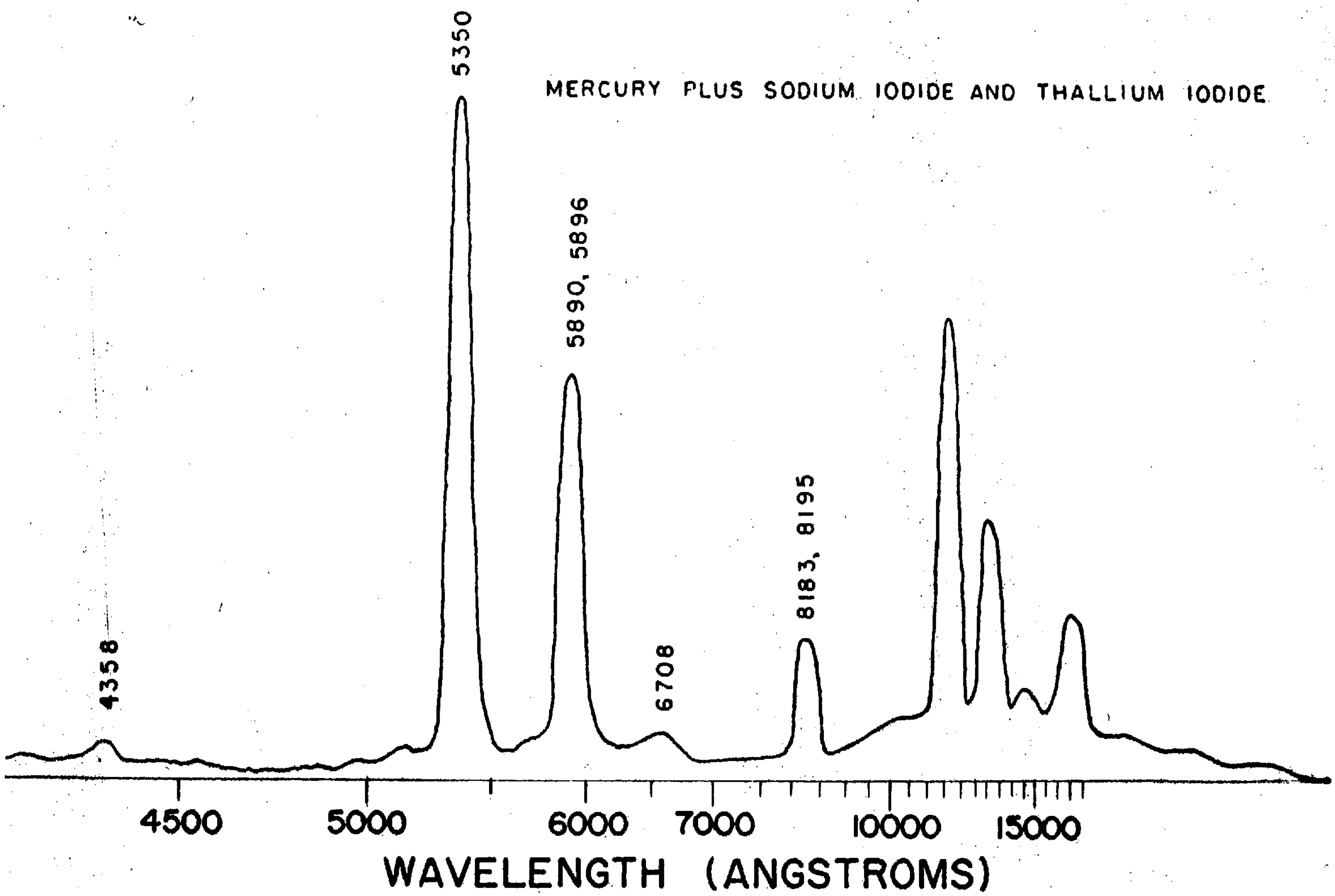
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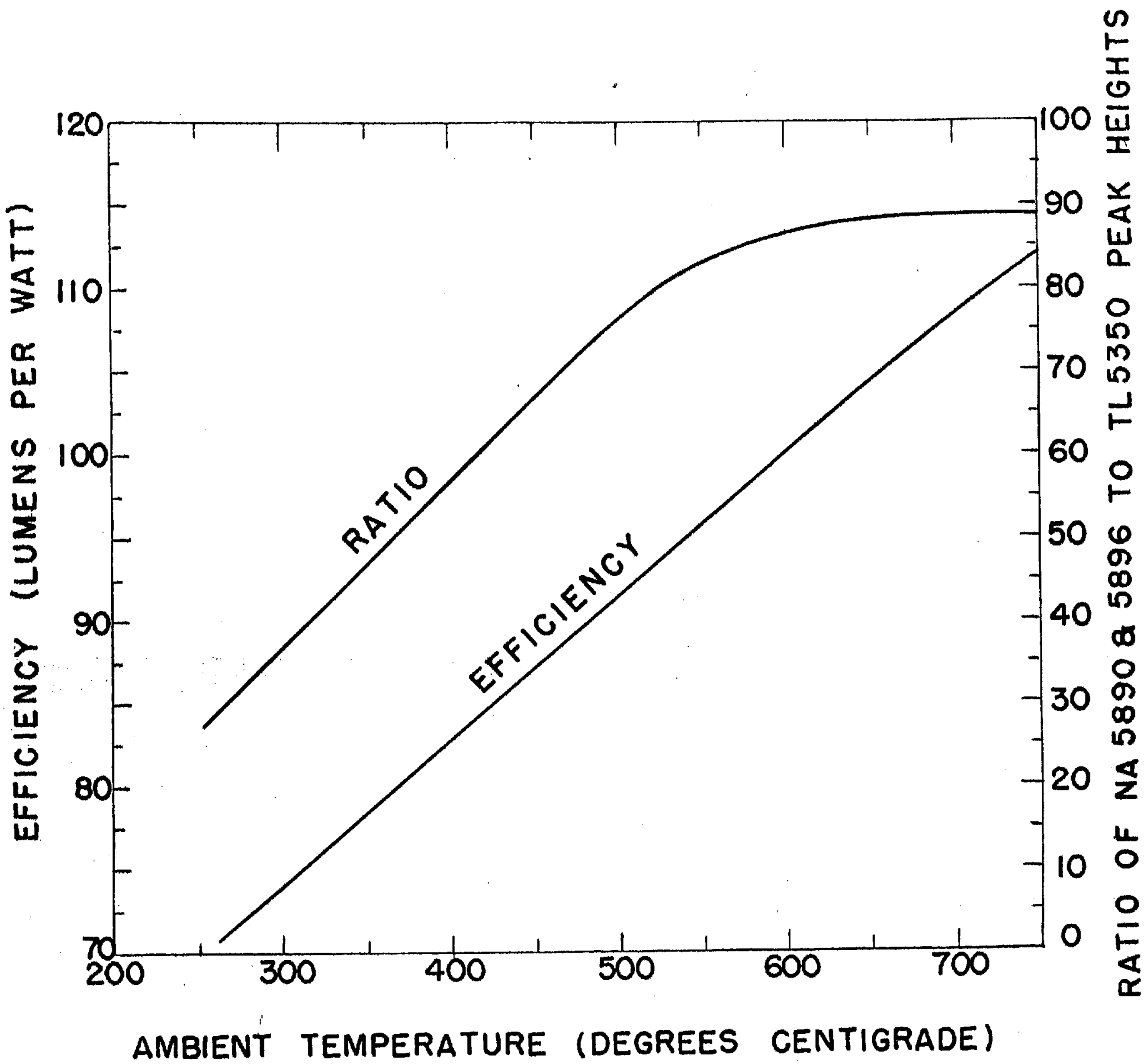
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110
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80
70
RATIO OF NA 5890 & 5896 TO TL 5350 PEAK HEIGHTS
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90
80
70
60
50
40
30
20
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RATIO
EFFICIENCY
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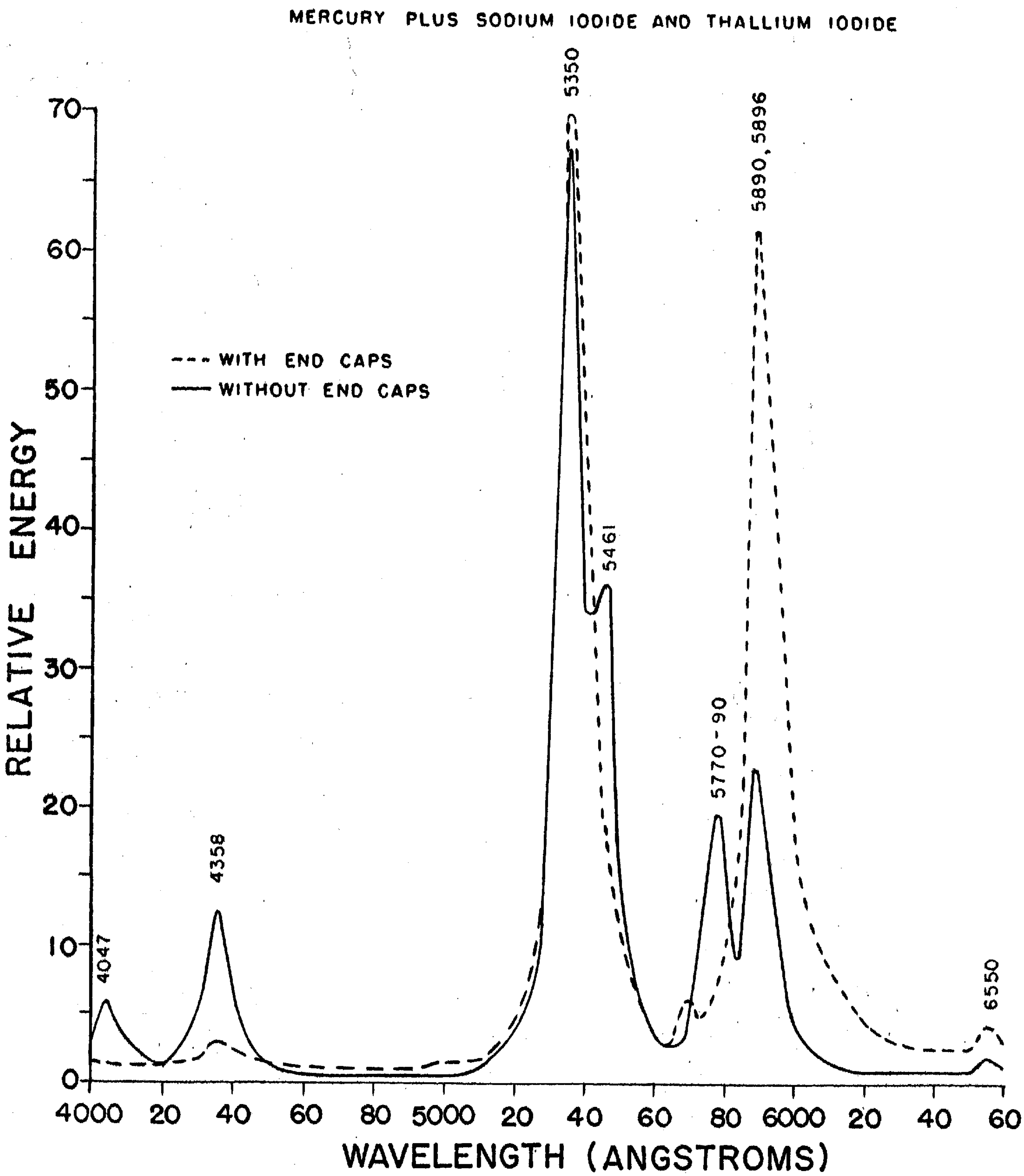
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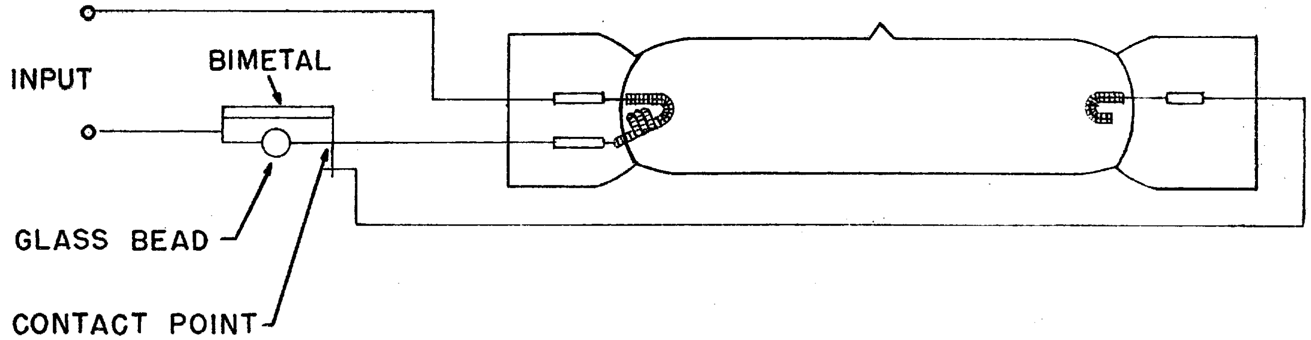
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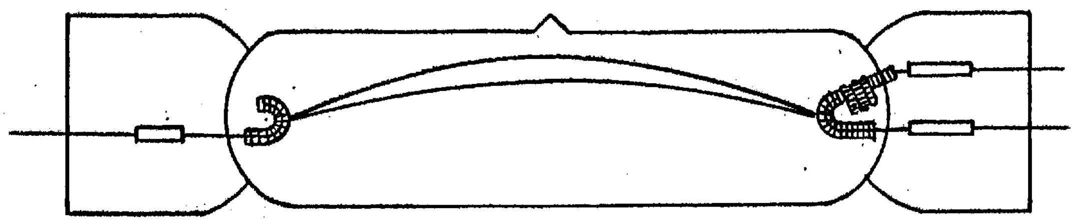

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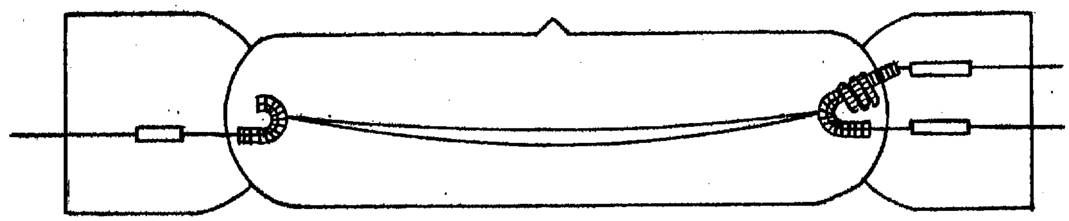

WITH MAGNETIC FIELD

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RESPONSIBLE COMPONENT

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PRIORITY ______ DATE REQUIRED 16 September 1965

1. BACKGROUND INFORMATION:

The work requested is in support of an NPIC : __ Photo interpretation proj.; X Non-photo interpretation project. It will result in: __ Hard copy report; __ Informal report (memo); X Basic service only.

Project Description: Rear-Projection Light Source Study.

2. SPECIFIC SUPPORT/SERVICE REQUESTED: Support from NPIC will probably consist of: __ Photographic; __ Reproduction; __ Mensuration; __ Graphics; __ ADP; __ Editing; X Other (explain below) -- (Include statement as to estimated amount of work required of support component(s); i.e., number of contact prints, enlargements, boards, etc.)

This project covers the implementation of some subjective tests to determine the best light sources for rear-projection viewing. The tests will be conducted in conjunction with the P&DS/EDLB.

3. URGENCY JUSTIFICATION: (If immediate support is required a statement of justification must be made on this form.)

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